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The Starting of Fluorescent Lamps

By D. T. WAIGH, B.Sc., A.Inst.P.(*Member*), and
L. C. WILTSHIRE, M.Sc., A.Inst.P.

Summary

Methods of starting hot-cathode fluorescent lamps may conveniently be divided into three categories, which together cover most, if not all, of the common starting devices. The paper discusses the processes occurring and the factors which affect the ease of starting when a lamp is started by means typical of each of these basic methods. Data are given which show how starting is affected by lamp parameters and conditions external to the lamp. The choice of starting method is briefly discussed with reference to the limitations of the more common types.

(1) Introduction

The term "starting voltage" (or "striking voltage") of a discharge lamp is commonly used and understood to mean "the lowest voltage at which the lamp will strike." In the days when only "switch-start circuits" were used for hot-cathode low pressure lamps, this definition applied as well to them as to cold-cathode lamps and high pressure lamps, but the introduction of other starting devices has made it necessary closely to specify the conditions of operation in order to give meaning to the term.

There are several hundreds of patents relating to starting devices, but it is possible to place them in three categories according to the way in which the cathodes are brought to emission temperature, an essential condition for full, normal lamp operation.

The other condition which must exist before a lamp will start is that there must be a potential gradient along its length of sufficient magnitude and duration to initiate ionisation of the gas in the lamp.

These two requirements are met in different ways by different types of starting device, and this frequently results in variation in performance according to type as other conditions are varied.

The first of the three categories referred to in section (3.2.1) as "cold-starting" is typified by the American instant-start* transformer, which is essentially the same as a transformer for use with cold-cathode lamps. This is given precedence in order to obtain a more logical sequence and for no other reason. It was not first historically nor is it first in importance.

Typical of the second category, which is referred to in section (3.2.2) as Pre-heat, is the glow switch, the design of which can influence lamp starting very substantially. In view of this, and the continued popularity of this type of starter, factors affecting glow-switch design are considered in some detail.

The third category referred to under section (3.2.3), Continuous Cathode Heating, includes all types of circuits with auxiliary cathode heating arrangements. The best known of these are the quick-start types (also known in this country as instant-start), long established for general lighting use and also noteworthy for dimming and flashing applications. The newer American rapid-start also belongs to this class.

In addition to the starting device and the lamp itself, ease of striking may depend on other factors external to the lamp, e.g., atmospheric temperature and humidity. The effects of several of these factors are considered separately under the appropriate headings.

The manuscript of this paper was first received on July 23, 1956, and in final form on October 9, 1956. The paper was presented at a meeting of the Society held in London on November 13, 1956.

*In the authors' opinion the use of the term "instant-start" for circuits with auxiliary cathode-heating is unfortunate and leads to confusion, particularly in the export field.

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(2) The Starting Process

The current in a low pressure discharge is carried mainly by electrons, which are produced by collision processes in the gas and vapour, and by emission from the cathodes. Electrons are removed by recombination with positive ions in the gas and at surfaces within the lamp. Positive ions are also produced by the same collision processes and help the flow of current by neutralising the space-charge, which would otherwise limit the flow of electrons, and by releasing electrons from the cathodes by bombardment.

Under normal running conditions, with the current stabilised by some form of ballast, the number of electrons produced balances the number lost.

The process of starting a lamp is one of multiplication of the number of electrons (and ions) present in the lamp before the application of the starting potential. There may be a large number of electrons present due to emission from heated thermionic cathodes, or there may be only a few which are present as a result of cosmic rays or traces of radio-active material; from these the multiplication process starts.

When a voltage is applied between the electrodes of a low pressure discharge tube, the number of electrons arriving at the anode for each one leaving the cathode will either be greater than or equal to one, in which case current will flow, i.e., the discharge will start, or it will be less than one and the discharge will fail to start. This means that, in the former case, the number of electrons produced by collision is at least equal to the number lost by re-combination in the gas and at the walls.

With the first type of starting, which we refer to as "cold-starting," there are no thermionically-produced electrons and therefore a high voltage is required to accelerate very rapidly the few electrons present, so that each produces considerable ionisation in its path down the tube and does not readily drift to the walls. The process of multiplication of electrons proceeds rapidly and the positive ions which are produced at the same time raise the temperature of the cathodes by bombardment. If, as in some cold cathode tubes, the cathodes are not coated with a thermionic emitter, this increase of temperature makes little difference to the electron emission and the increase in current proceeds smoothly. With thermionic cathodes, however, there is a sudden increase in the number of electrons present when emission temperature is reached and the lamp current rises rapidly to a value limited by the ballast.

In the second method of starting, the pre-heating of the cathodes provides a large number of electrons localised at each end of the tube and it is only necessary to apply a voltage pulse of sufficient magnitude and duration to send them along the tube, producing enough ionisation on the way for the arc to be sustained—thereafter being maintained by the available R.M.S. voltage.

In the third method, the heating of the cathodes by current supplied from a transformer provides an adequate quantity of electrons at each end of the tube, but only the supply voltage, and no (relatively) high voltage pulse is applied across the lamp, instead, an earthed conductor is placed close to the lamp. A high potential gradient is thus produced between one electrode and this conductor, which causes local ionisation. The lamp will start if the combined effect of the voltage across it and the external field is sufficient to draw electrons from one end to the other inside one half-cycle. The time of starting from the moment of switching on is determined by the time taken to heat the cathode and may be between half a second and several seconds.

The method of starting on frequencies of 400 c.p.s. and above,[1] with the circuit components suitably chosen so that adequate cathode heating is supplied, is essentially that of "method 3."

This method, which is characterised by the simultaneous application of the cathode heating and the ionising voltage (the latter being insufficient by itself to cause starting) may be modified by the introduction of a pulse, prior to cathode heating.

(3) Factors Affecting Lamp Starting

A convenient figure to serve for comparison of lamp starting qualities is the striking voltage, which may be specified in one of three ways according to which of the three types of circuit discussed above is employed.

(a) In the cold starting type of circuit the lamp striking voltage is the lowest R.M.S. voltage which must be applied across the lamp to initiate the discharge and bring it to a stable arc condition.

(b) Starter switch circuits make use of a high voltage pulse to start the discharge; we therefore refer in this case to the pulse striking voltage, which is taken to be the peak voltage of a pulse that is just sufficient to give reliable starting. The pulse duration also needs to be specified.

(c) In circuits using continuous cathode heating the lamp striking voltage is defined as in (a) but with the assumption, except where otherwise stated, that the cathodes are at full emission temperature. For convenience the term "quick-start striking voltage" will be used for these conditions.

The striking voltage of a lamp in any type of circuit depends on many variables, some of which are associated with the lamp itself, some with the circuit components, and some with completely external conditions. It is not practicable, therefore, to consider the effect on starting of all these variables acting simultaneously, so the figures given relate mostly to commonly occurring values of the variables. Except where otherwise stated the figures refer to low-pressure mercury discharge lamps filled with argon at a pressure of 3 mm. Hg. in an ambient temperature of 20 deg. C. and relative humidity not greater than 70 per cent.

(3.1) The Lamp Itself

(3.1.1) *Physical Dimensions*

Two variables are involved here, namely length and diameter. It is generally known that the striking voltage increases as the length increases, perhaps less well known that it increases as the diameter decreases.

Fig. 1 shows how the pulse-striking voltage varies with length of lamp for tube diameters of $\frac{5}{8}$ in., 1 in. and $1\frac{1}{2}$ in.

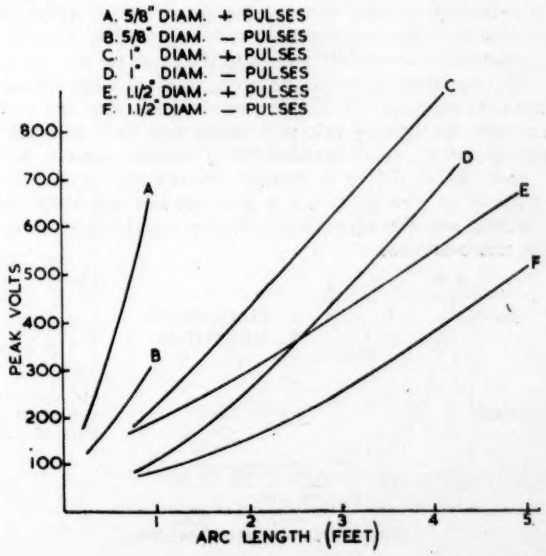

Fig. 1. Variation of pulse-striking voltage with arc length and tube diameter. (Pulse time-constant, 500 micro-seconds).

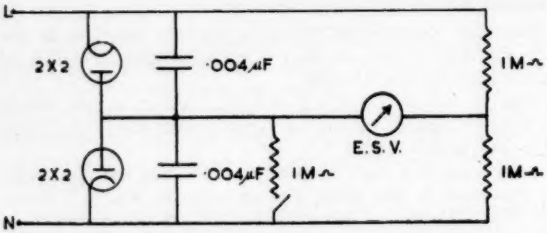

Fig. 2. Peak voltmeter, sensitive to positive or negative pulses.

For the experimental measurements, the pulses were produced by the discharge of a capacitor through a resistance, circuit values being chosen to give a pulse shape similar to that produced by a starter switch. In this way pulses of any desired peak value could be obtained, the peak value of the pulses being read on a peak voltmeter (see Fig. 2). When, as is usually the case, one electrode of the lamp is at neutral potential during starting, the polarity of the starting pulse is taken to be the polarity of the voltage applied to the other electrode. As can be seen from the curves (Fig. 1) the striking voltage for positive pulses is between 100 and 150 volts higher than for negative pulses. This is due to the electric field being concentrated in the neighbourhood of the electrode which is at a higher voltage relative to earth. When this electrode is negative with respect to earth, electrons are ejected from it and travel towards the other end of the tube; a positive potential on the other hand tends to prevent electrons travelling down the tube. This asymmetry of the pulse-striking voltage can lead to uncertain starting behaviour when the lamp is used with a starter switch of asymmetrical design.

The increase in striking voltage with decrease in tube diameter can be explained by the greater rate of loss of ions and electrons by diffusion to the walls in the narrower tube.

When pulses of very short duration are used it is found that a higher peak value is required to initiate the discharge. To define the pulse duration precisely it is necessary to refer to the pulse shape. For starter switches the shape of the pulse is approximately exponential, with superimposed high-frequency components, and it is convenient to specify the pulse duration by the exponential time constant. Fig. 3, curve A, shows how the negative pulse-striking voltage of a 5-ft. lamp varies with the time constant. It will be seen that provided the time constant exceeds 150 micro-seconds, the striking voltage depends very little on pulse duration, and in fact starter-switch pulses are found normally to be around the 1,000 micro-second region. Curve (B) in Fig. 3 is derived theoretically on the assumption that the lamp will strike if the voltage across it does not fall below 400 volts for a period of 50 micro-seconds, and the agreement with the experimental curve is reasonably good down to 30 micro-seconds.

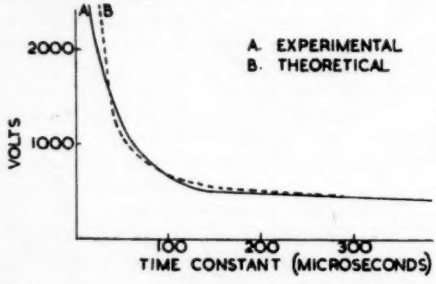

Fig. 3. Variation of pulse-striking voltage with pulse time-constant for a 5-ft., 1½-in. diameter lamp.

(3.1.2) *Gas Pressure*

The way in which gas pressure influences striking voltage can be seen from the curves given in Fig. 4, relating to quick-start operation. A minimum striking voltage is obtained at a certain pressure which bears a linear relationship to arc length, as shown in Fig. 5. Except in the case of the shorter lamps, not more than 3 ft. in length, the pressure giving minimum striking voltage is too low to be used because of serious reduction in lamp life. The existence of a minimum in the striking voltage/pressure curve can be explained by the presence of two opposing factors, one being the loss of electron energy due to multiple collisions with gas atoms, which becomes more serious at high pressure. The other factor is the loss of ions and electrons by diffusion to the walls of the tube, which becomes more rapid with lower pressure.

(3.1.3) *Gas Composition*

Gases other than argon have been used for lamp filling; krypton, for example, has been found[2] to give higher lamp efficiencies, but this is accompanied by higher striking voltage. The pulse-striking voltage for krypton-mercury-filled lamps is about 50 per cent. above that for argon-mercury filling, and the lamps will not start satisfactorily on normal quick-start or rapid-start circuits. A reason for this behaviour is

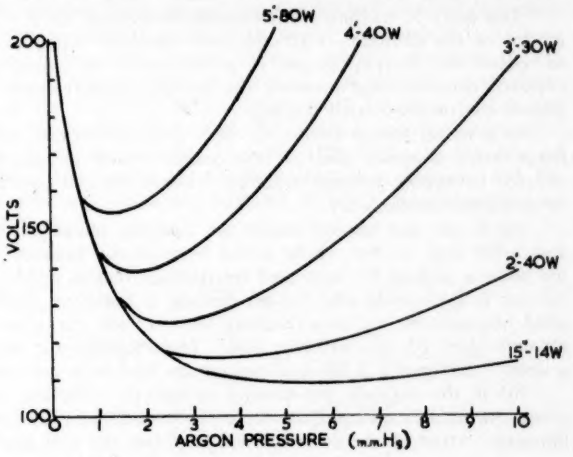

Fig. 4. Variation of quick-start striking voltage with argon pressure for 1½-in. diameter lamps with an earthed plate ½-in. distant.

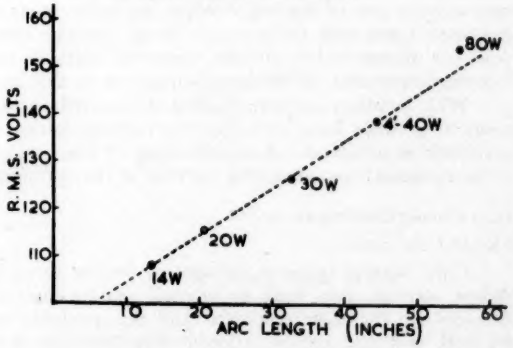

Fig. 5. Variation of minimum quick-start striking voltage with arc length for 1½-in. diameter lamps.

the existence of energy levels of krypton below the ionisation potential of mercury; a transfer of electron energy to krypton atoms occurs which reduces the probability of mercury atoms being ionised.

(3.1.4) *Gas Purity*

Traces of impurity in the gas generally affect the starting qualities of a lamp adversely. Impurities may arise by the accidental introduction of volatile or gaseous material into the lamp before or during the evacuation process. There may be residues from the decomposition of the phosphor binder or the cathode emissive material; for example, H_2O, CO, CO_2 or organic vapours. Other impurities, such as N_2, O_2, and oil vapour from the pumping system, may be introduced with the argon filling. Provided the amount of impurity is small, it tends to disappear during the running of the lamp by combining with the mercury or material of the cathode. In certain cases the impurity may become adsorbed on the phosphor surface. The effect of the impurity is usually to increase the striking voltage considerably, and often to "poison" the cathode so that electron emission is much reduced. The increase in striking voltage is caused by the absorption of electron energy through inelastic collision with impurity molecules.

(3.1.5) *Cathode Conditions*

The delay in starting a hot-cathode fluorescent lamp is due entirely to the thermal inertia of the cathode. Cathodes are therefore made as small as possible in order to reduce this thermal inertia to a minimum. A coiled coil tungsten filament with emissive material held between the turns is a convenient form of cathode for cold as well as for pre-heated starting.

In a starter-switch circuit, the time required for the cathode to reach its operating temperature depends also on the starter-switch design, the ballast design, and is affected by supply voltage variation. There are two conditions in which starting can be achieved satisfactorily :—

(a) If the pre-heating raises the cathode temperature to between 800 deg. C. and 1,000 deg. C. the whole active area of the cathode emits electrons, and when the pulse is applied the saturated emission current is sufficient to supply the arc. Once the arc is established and the pre-heating is removed, cathode heating energy is supplied not only by the ions reaching the cathode, but also by the arc current flowing through part of the cathode coil. Nevertheless, the emission is concentrated in a small "hot spot" at the end nearest the lead-wire carrying the current.

(b) If the cathode pre-heating current is sufficient to produce a voltage drop across the cathode greater than about 8 volts R.M.S., a local arc forms across the cathode filament. Most of the current then by-passes the coil and a pair of hot spots form, one at each end of the coil. When the pulse starts the main discharge, one of these hot spots takes over the main discharge and the other cools. This is the ideal condition for starter-switch circuits, since the cathode is never subjected to severe ion bombardment and the striking voltage is at a minimum.

With auxiliary cathode heating it is usually arranged for this heating to be sufficient to produce local arcs, but the striking voltage reaches its minimum before this condition is achieved. A modification of the quick-start circuit to enable the lamp to be dimmed[3] maintains the cathode at the optimum temperature for starting.

(3.2) Circuit Conditions

(3.2.1) *Cold Starting*

Cold starting requires voltages of two or three times the normal supply voltages unless starting aids such as internal conducting strips are used. Step-up transformers are therefore employed and the available starting voltage is limited mainly by bulk and cost considerations. The load characteristics of the transformer must

be designed to permit a rapid transition from the glow to the arc condition in the lamp, to ensure satisfactory starting and adequate cathode life.

(3.2.2) *Pre-heat (Starter Switch) Circuits*

In pre-heat circuits the magnitude of the pre-heating current is determined by the ballast characteristics, but other aspects of starting are governed mainly by the starter switch[4].

Although other types have been designed, the familiar glow and thermal switches are the only automatic starter switches in general use.

The type of start provided by a well-made thermal switch is the ideal " pre-heat plus pulse," in which the switch contacts are closed initially and open only after the lamp cathodes are properly heated. The pulse produced when the contacts open must be sufficient to guarantee immediate starting, because if a second attempt is necessary the slow re-setting of this type of switch causes long delay and much inconvenience.

For most purposes the glow switch has ousted the thermal type owing to its advantages in simplicity, cost, robustness and some operating characteristics.

Glow switches require a short time for the contacts to close after switching on; this closing time depends on the sensitivity of the bimetallic element, and on the glow current, which in turn depends on the gas pressure and on the supply voltage. Rapid closing is obtained by a thin, sensitive bimetal, and the highest gas pressure consistent with other requirements. If the electrodes of the glow switch are unequal in area or have different surface materials the glow current depends on the direction of the current, in other words the switch acts as a partial rectifier. The greater current flows when the larger electrode, or the electrode with a lower work function, acts as the cathode. This situation gives rise to difficulties when the switch is used in a capacitive circuit or when two such switches are operated in series (Fig. 6A). In the case of the capacitive circuit the D.C. component of the glow current is blocked and the resultant mean current is diminished, whilst two switches in series will suffer reduced

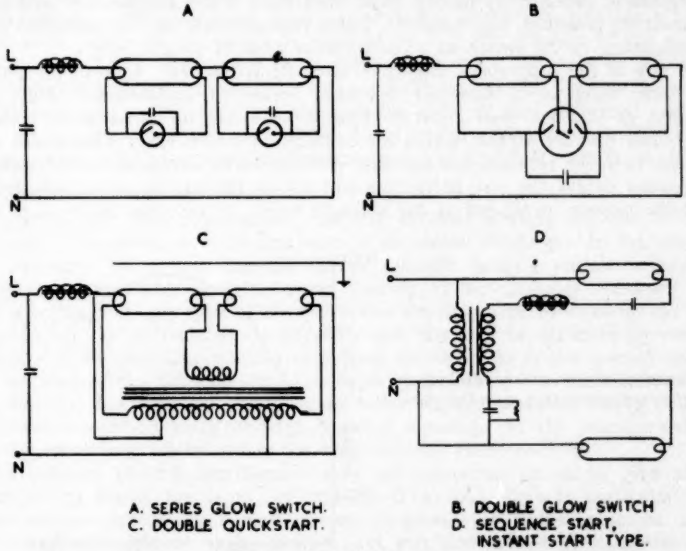

Fig. 6. Series lamp circuits.

glow current if they rectify in opposite directions. In view of these difficulties a switch of symmetrical design is desirable to obtain a consistently short closing time.

The period during which the switch is closed is the time allowed for the lamp cathodes to heat up, and is determined by the temporary welding together of the contacts caused by the discharge current of the radio interference suppression capacitor, and also, in certain switch designs, by the thermal inertia of the bimetal. Pre-heat periods tend to vary much more than with the thermal switch, but the glow switch has the advantage that if the lamp fails to start the first time the switch opens, immediate reclosure takes place and a further pre-heating occurs before another attempt is made to start the lamp. By a suitable choice of bimetal material an average pre-heat period of ½ to 1 sec. is obtainable when a .006 microfarad capacitor is used across the switch.

In the event of lamp failure due to cathode deactivation, the starter switch will operate continuously and this may overheat the ballast and reduce the life of the switch. A thermal cut-out is therefore sometimes included with the switch to break the circuit if the switch operates for more than a limited period of time. Re-setting of the cut-out is accomplished either manually or, in certain designs, automatically when the circuit is switched off.

The interruption of the pre-heating current at the moment the starter switch opens gives rise to a voltage pulse provided there is appreciable inductance in the ballast. The peak value of the pulse is determined mainly by the instantaneous value of the current and the starter switch characteristics and does not depend much on the size of the inductance, provided this is not very small. Pulse duration is, however, largely controlled by the inductance; a very small inductance may give difficult starting because a very short duration pulse is produced and a correspondingly higher peak is required. If the ballast contains no inductance the peak voltage available is no greater than the peak of the supply voltage.

The damping effect on the pulse caused by the glow discharge between the contacts of the switch is governed by the same factors that control the glow current. A high pulse is obtained by having small electrodes, a low gas pressure and a gas of high ionisation potential, e.g., helium. These requirements are in opposition to those for rapid closing of the switch so a compromise must be sought.

The size of the suppression capacitor also affects the peak value of the pulse to a small extent; there is, in fact, an optimum value of capacitance (Fig. 7). An explanation of this has been given by Rixton[4]. When no capacitor is present the voltage builds up very rapidly across the contacts as they break. This allows a metal vapour arc to form between the contacts which absorbs energy from the inductance. The capacitor delays the rise in voltage and allows the gap to widen sufficiently for the metallic vapour, produced as the contacts break, to disperse before it is ionised.

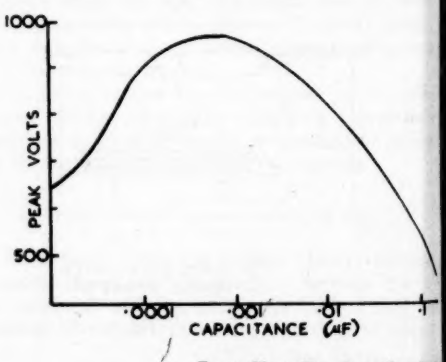

Fig. 7. Variation of glow-switch pulse voltage with interference suppression capacitor value.

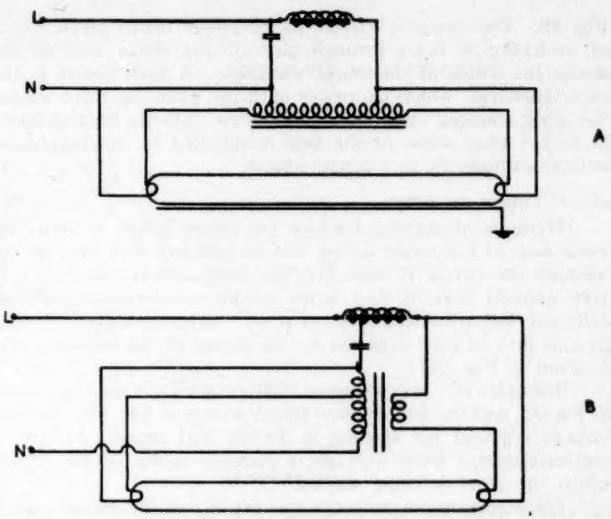

Fig. 8. (A) Quick-start circuit with step-up connections. (B) Pulse-start circuit.

Thus it is apparent that the interference suppression capacitor can usefully affect both pre-heat time and pulse voltage as well as fulfil its intended purpose.

A glow switch having electrodes of unequal size results in peak values of pulse being dependent on the direction of the current at the moment the switch opens. The effect of this on the lamp can be to cause failure to start when the switch is inserted one way, but satisfactory starting can be achieved if the switch is reversed in its holder. As an example, consider the case of a 5-ft. 80-watt lamp, requiring pulses of +600 volts or −450 volts peak, using a glow starter switch giving pulses of 350 volts and 500 volts peak. If the switch is inserted so that the polarity of the pulses, as defined earlier (3.1.1), correspond to + 500 volts and − 350 volts it is clear that neither pulse is sufficient to start the lamp. Reversal of the switch gives pulses of +350 volts and −500 volts and the negative pulse is then sufficient. Absolutely reliable starting therefore requires a symmetrical switch giving at least 500 volts peak pulse, or alternatively an asymmetrical switch giving at least 650 volts in one direction.

(3.2.3) *Continuous Cathode Heating*

In quick-start and rapid-start[5] circuits cathode heating current is supplied by an auxiliary transformer with low voltage secondary windings. In the interests of overall efficiency, the power required by the cathode heating circuit is kept to a minimum consistent with an initial rapid heating of the cathodes necessary to gain the full advantage of this type of circuit. Once the discharge commences the cathode heating current can be reduced considerably and this may be achieved by connecting the primary of the auxiliary transformer across the lamp, as in the normal quick-start circuit, so that nearly the full supply voltage is applied to the transformer primary during starting, but only the much lower lamp voltage when the lamp is running. An alternative method is to arrange bucking windings on the transformer which reduce the secondary voltage when the lamp current starts to flow.

The cathode heating transformer may be connected so as to give an extra 20 volts or so across the lamp for starting (Fig. 8A). This is particularly useful for low voltage supplies but may not be desirable for higher voltages as there will be a tendency for some lamps to start cold, with detrimental effects to the cathode.

"Pulse-start" circuits are numerous and varied, but basically are similar to

Fig. 8B. The charging current to the power factor correction capacitor at the instant of switching-on flows through part of the choke and so develops a high voltage across the whole of the choke windings. A flash occurs in the lamp, followed by a glow discharge, which continues until the cathodes reach emission temperature, when the glow changes over to an arc. Less cathode heating is required with this type of circuit since some of the heat is supplied by ion bombardment, which inevitably reduces cathode life to a certain extent.

(3.2.4) *Lamps in Series*

Methods of starting for two (or more) lamps in series can be classified in the same way as for single lamps, but in addition they may be subdivided according to whether the circuit is such that the lamps always start in a particular order. It is very unlikely that, in any series circuit, simultaneous starting of the two lamps is achieved, but in circuits referred to as " sequence-start ([8, 9]) the same lamp is enabled to start first on each occasion by the nature of the circuit, a typical example of which is given in Fig. 6D.

Examples of " non-sequence " series operation are the " double quick-start " shown in Fig 6C, and the double-glow switch shown in Fig. 6B. In these types of circuits the voltage required for starting is double that needed for one lamp, whereas in the sequence-start a lower voltage is possible owing to the " by-passing " of one lamp whilst the other is being started.

The advantage of sequence-starting is that the ballast size is reduced, particularly when " cold-starting " by leaky-field transformer is employed; but lamp life is reduced, partly through the poor lamp-current wave-form and partly through the prolonged glow-arc transition which increases cathode bombardment.

When the sequence-start was first introduced in the U.S.A. serious lamp-life troubles were experienced and, as a result, minimum glow currents during the starting cycle were specified but the life was still reduced by about 33 per cent. This was not considered to be important([9]) compared with the advantage gained, viz., cheaper, smaller ballasts with lower losses.

(3.3) External Conditions

(3.3.1) *External Conductors*

Before the discharge has started in a lamp the electric field in the space surrounding the electrode is not confined within the glass tube but extends some considerable distance beyond the walls. It is not surprising, therefore, that the electric field within the tube can be influenced considerably by external conductors, and this influence shows up in the striking voltage of the lamp. Fig. 9 shows how the quick-start striking voltage of a 5-ft. 80-watt lamp varies with the distance of an earthed plate,

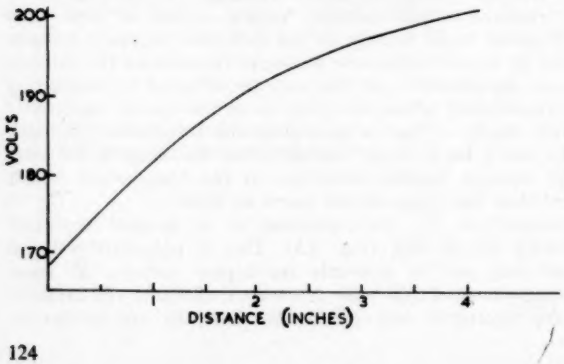

Fig. 9. Variation of 5-ft. 80-watt quick-start striking voltage with earthed-plate distance.

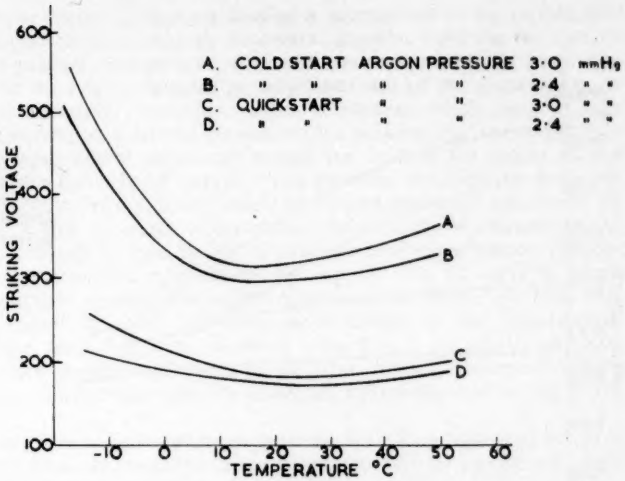

Fig. 10. Variation of striking voltage with temperature for a 5-ft. 1½-in. diameter lamp, showing effect of argon pressure.

and it is clear that without this form of starting assistance the 5-ft. lamp would not be suitable for quick-start operation at the lower supply voltages.

This effect is dependent on the area of the earthed plate as well as the distance, a wire of small diameter on the lamp surface being less effective than the metal work of a fitting an inch or more from the lamp.

Pulse striking voltages are similarly influenced by earthed conductors, but it is not necessary to resort to this form of starting assistance if the starter switches are designed to provide the higher striking voltage necessary in the absence of starting aids.

(3.3.2) *Temperature*

All forms of lamp starting are affected by ambient temperature(6), a result of the dependence of mercury vapour pressures on temperature. From 0 deg. C. to 35 deg. C. a tenfold increase in mercury vapour pressure occurs, although fortunately the variation in striking voltage is very much less in proportion. A minimum striking voltage is obtained at a particular temperature, corresponding to the pressure of mercury vapour which leads to the most efficient ionisation of the mercury atoms. In Fig. 10 curves C and D show the variation of quick-start striking voltage with temperature, and here the minimum occurs around 30 deg. C. The reason for the existence of the minimum can be seen in a general way by considering the effect of very low and very high mercury vapour pressures. At very low vapour pressures, i.e., low temperatures, mercury atoms are very scarce and ionisation of argon atoms is necessary to start the discharge; as the ionisation potential of argon is 50 per cent. higher than that of mercury this means a higher starting voltage. When the mercury vapour pressure is high, there is greater loss of electron energy through non-ionising collisions. Somewhere between the two extremes there is a condition where sufficient mercury atoms are present to supply ions without absorbing too much energy from the electrons.

The increase in striking voltage at low temperatures leads to difficulties in starting, particularly in quick-start circuits. One way out of this difficulty is to use lower gas pressure when, as can be seen from Fig. 10, the striking voltage at a given temperature is lower; the same also applies to the arc voltage, so the discharge is more easily maintained. Lowering of gas pressure is, however, limited by the adverse effect on life and a compromise is found between 2.0 and 2.5 mm.

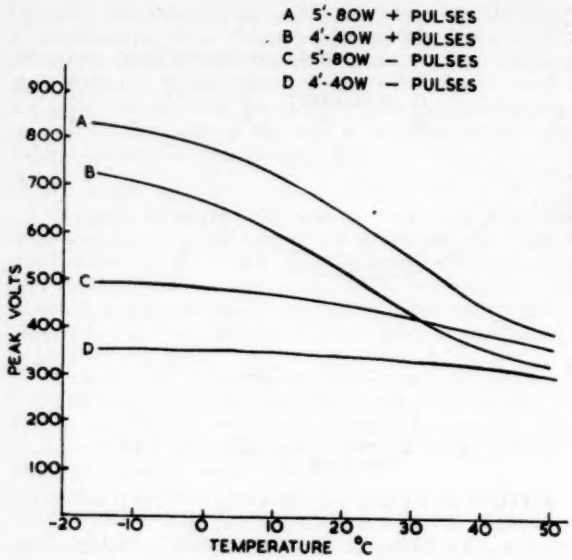

Fig. 11. Variation of pulse striking voltage with temperature for 1½-in. diameter lamps. (Pulse time-constant 500 micro seconds.)

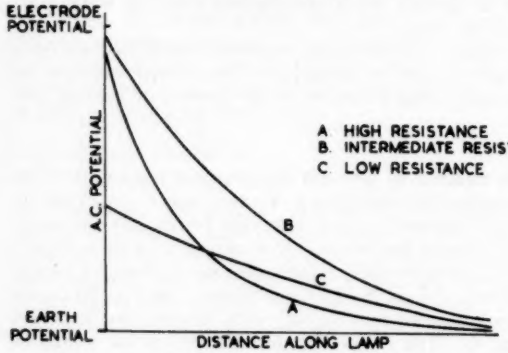

Fig. 12. Theoretical potential distributions along a lamp tube showing the effect of different surface resistances.

In the case of the cold-start striking voltage, also shown in Fig. 10 curves A and B, a much smaller relative improvement is possible by lowering the gas pressure.

Some improvement in starting at low temperatures is also obtained by using a capacitive ballast, or "leading" circuit.

The variation of pulse striking voltage with temperature does not show such a pronounced effect as quick-start striking voltage. In particular it is seen in Fig. 11 that the negative pulse striking voltage varies little with temperature. Such differences suggest that the mechanism of ionisation may be different in the two cases; it is possible, for instance, that negative pulses produce ionisation mainly of argon atoms, the concentration of which is independent of temperature.

(3.3.3) *Humidity*

It is well known that high atmospheric humidity can make lamp starting difficult, particularly with cold-start and quick-start types of circuit(7).

The effect of relative humidity on lamp starting is entirely due to the surface film of moisture which forms on glass at high humidities, thereby lowering the surface resistance. When the surface resistance is very high, the presence of the glass tube has very little effect on the electric field in the neighbourhood of the electrodes prior to the initiation of the discharge. Very low surface resistances, which occur at high humidities, can assist starting in a similar manner to the adjacent earthed conductors discussed earlier, but intermediate resistances reduce the field in the region of the electrodes and so increase the striking voltage. The potential distributions along the outside wall of the lamp for three different values of surface resistance are shown by the curves A, B and C in Fig. 12, which were obtained theoretically by considering the resistance-capacitance network formed by the electrode-to-tube capacitances, tube-to-earth capacitance and tube resistance, illustrated by Fig. 13. Fig. 12 curve B, which minimises potential gradients, corresponds to the condition when the surface resistance from end to end is equal to about 3.8 times the reactance of the tube-to-earth capacitance. In practice, for a 5 ft. 1½ in. diameter lamp, ¾ in. from an earthed plate, this means that a surface resistance of about 60 megohms gives a maximum striking voltage, and this agrees satisfactorily with the measured figures depicted by the curve in Fig. 14.

Starter switch circuits are not affected by the increase in striking voltage of lamps at high humidities because normally these circuits are designed to provide a sufficiently high peak voltage to cover the requirements at all humidities.

One exception to this is the starter switch used in conjunction with a resistive ballast without an inductive component. Here the maximum peak voltage cannot exceed the peak mains voltage and starting conditions are similar to those in the quick-start circuit.

In " pulse-start " circuits the maximum pulse, i.e., that obtained when closure of the main switch occurs at the peak of the supply voltage wave, is sufficient to start the lamp under the most adverse conditions, so that by repeated switching it is always possible to make a lamp start.

Cold-start and quick-start control gear would need to be of uneconomic design to provide the excess voltage required, so the lamps used with this type of gear are treated to prevent the surface resistance change. One treatment is the application of a water

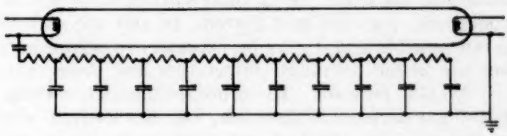

Fig. 13. Equivalent circuit of tube surface resistance and capacitance to earth.

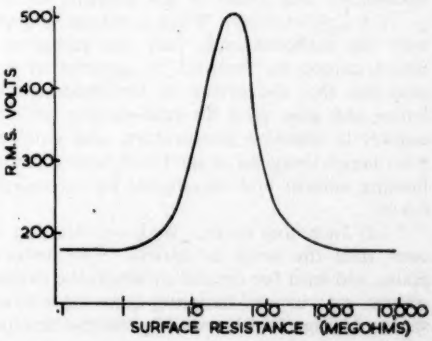

Fig. 14. Variation of 80-watt quick-start striking voltage with the resistance of the external surface of the tube.

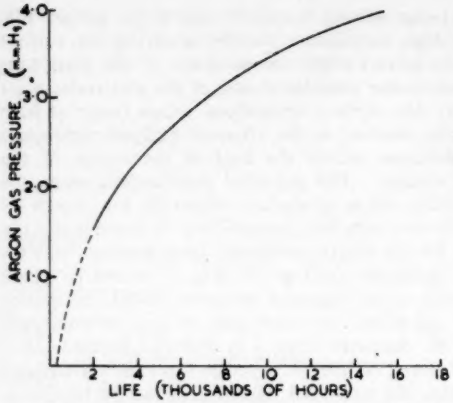

Fig. 15. Variation of lamp life with gas pressure.

repellent material to the glass, usually a silicone substance for durability; provided the tube remains clean, water will not form in a continuous film over the surface and the resistance remains high at all humidities. Another method is the attachment of a strip of conductive material along the length of the tube; this has the effect of maintaining a very low surface resistance and at the same time providing a convenient earthed conductor for reducing the striking voltage.

(4) The Effect of Starting on Lamp Life

The majority of fluorescent lamps fail because the emissive coating on one or both cathodes has been used up. The length of life, therefore, depends on the amount of coating initially on the cathode and the rate at which it is removed. Removal of the coating occurs through slow evaporation during running and more-or-less violent disintegration during starting. Factors which affect the amount of disintegration during starting are:—

(a) *Cathode design.* Cathodes must be designed to suit the normal running conditions of the lamp. With most starting devices it is then possible to arrange starting conditions, e.g., pre-heat current, to suit the cathode. In some cases, however, this is not possible and it may be necessary to compromise by using a cathode which does not run at the optimum temperature and some reduction in life results.

(b) *Gas pressure.* To ensure satisfactory starting, particularly at low temperatures, a low gas pressure is desirable, but this leads to shorter life so that a compromise is necessary. The effect of gas pressure on life is shown in Fig. 15.

(c) *Cold-starting.* When a voltage is applied which is sufficient to start a discharge with the cathodes cold, they are subjected to bombardment by high-velocity ions, which causes the removal of particles of emitter and consequent loss of life. It is desirable that the period of bombardment should be as short as possible, therefore lamps and gear used for cold-starting are designed to allow the cathodes to heat up quickly to emission temperature, and satisfactory life can thus be obtained. If, however, lamps designed to start with heated cathodes are supplied with inadequate cathode heating current and are started by increased voltage, a serious reduction in life may occur.

(d) *Switching cycle.* With any starting device there is some reduction in life for each time the lamp is started. This reduction is greatest when cold-starting takes place, and least for circuits in which the cathodes reach full emission before a discharge occurs, e.g., in well-designed quick-start circuits. The effect of switching cycle[10] is shown in Fig. 16. Curve A gives the results on 5-ft. 80-watt lamps with glow-switch

starting, and Curve B, the results given by Vorlander and Raddin[14] in 1950 for 4-ft. 40-watt lamps with glow-switch starting

The quantitative effect of any combination of the variables which affect life cannot easily be forecast from their effects separately. For example, a well-designed quick-start circuit may give lives 10-20 per cent. greater than a glow-switch with lamps of standard gas pressure, but the increase may be as high as 50 per cent. for reduced pressure lamps used for low temperature operation.

(5) Applications and Limitations

The main purpose of this paper has been to give facts and figures concerning starting methods, but the average user may find some difficulty when faced with the need to make a choice.

The choice of starting device depends on the condition of operation (taking into account the data given in the earlier part of the paper), cost (both initial and long-term), maintenance and possibly personal preference.

For the types of lamps in common use in Britain, the choice is practically limited to glow-switch or quick-start.

(5.1) Comparison of Starter-switch and Quick-start

Where conditions necessary to its use can be provided there is little doubt that the quick-start method has much to recommend it, but unfortunately the provision of these conditions sometimes involves restrictions which are unacceptable. The necessary conditions for reliable starting are :—

(1) Anti-humidity treated lamps (either metal-stripped or siliconed).
(2) A substantial area of metal, near the lamp, connected to earth or "dummy earth."
(3) Ambient temperatures around the lamp in the range 5 deg. C. to 40 deg. C.
(4) An actual supply voltage of not less than 188 volts.

These conditions exist, in the majority of industrial and commercial installations, and it is not difficult to show that, in the long run, the increased initial outlay com-

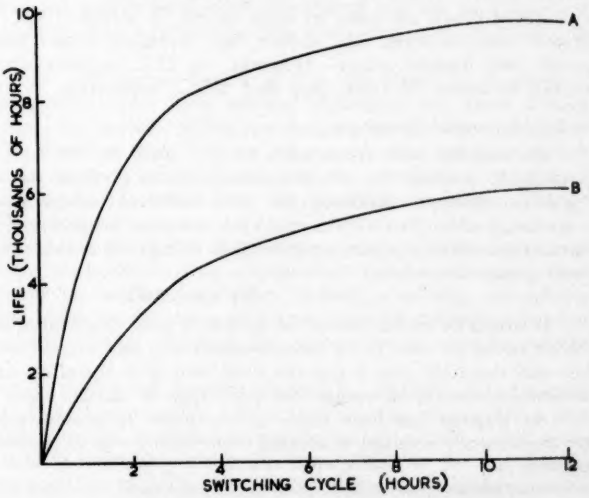

Fig. 16. Variation of lamp life with switching cycle.

pared with the glow-switch method is offset by longer lamp life and reduced maintenance cost. Compared with the quick-start method, the glow-switch has the following advantages :—

(1) Lower initial cost.
(2) Lower consumption (about 5 per cent. less) for the same light output.
(3) May be used in any fitting.
(4) Satisfactory operation over greater temperature range (0 deg. C. to maximum set by other components).
(5) No special lamps needed.

Disadvantages of the glow-switch are :—

(1) Although present-day glow-switches have long lives in normal use, they must eventually be replaced. In particular, they deteriorate rapidly if left in circuit for several hours with a faulty lamp. Because of this, " no-blink " switches with thermal cut-outs have been developed.
(2) Maintenance is not just a simple matter of lamp-changing but requires a little skill to determine which component, lamp or starter, is faulty.

(5.2) Starting Methods with Special Applications

(5.2.1) *Pulse-start*

Where there is an objection to the use of glow-switches, and conditions suitable for satisfactory quick-start operation do not exist for any reason, e.g., where it is inconvenient to stock special anti-humidity treated or metal-strip lamps, the " pulse-start " circuit has a distinct advantage.

Starting by pulse-start, however, causes a reduction in lamp life on a three-hour cycle, and it is therefore not advisable to use this circuit where a cycle of much less than six hours is usual.

(5.2.2) *Starter-switches for D.C. supplies*

Glow-switches are now available for use with single lamps on D.C. supplies in the range 200-250 volts, but where two lamps in series are to be used there is no alternative to a pair of thermal switches.

(5.2.3) *Lamps with Internal Starting Strips*

These lamps are used to some extent on standard A.C. supplies, but they have several disadvantages, e.g., shorter life, increased flicker and lower efficiency, compared with normal lamps. However, on D.C. supplies where the voltage is liable to fall to about 70 volts, they find useful application.

(5.2.4) *Resonant Circuits*

On supplies with frequencies of the order of 400 c.p.s. and above, it may be possible to arrange the circuit components to produce the conditions necessary for " good quick-start operation," i.e., only sufficient voltage across the lamp to produce a discharge when the cathodes reach full emission temperature. Unfortunately, resonant circuits are often designed to give high voltages and inadequate cathode heating and short lamp life results.

(6) Conclusion

It would be in the interest of simplicity and standardisation if one type of starting device could be used in all circumstances and had a clear advantage over all others, but unfortunately this is not the case, and it is therefore necessary to consider the advantages and disadvantages of each type of device under different conditions.

An attempt has been made in the paper to present enough information about the mechanisms involved in starting fluorescent lamps to enable users to avoid " starting trouble."

The authors are indebted to their colleagues for help in the preparation of this

paper, which is published by permission of the directors of Thorn Electrical Industries, Ltd.

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Discussion

C. E. WILLIAMS: The authors have attempted to bring together into an ordered form the scattered data on this subject. It is a pity that greater emphasis was not placed upon the importance of this problem as a central design aspect of fluorescent lamps and gear, governing as it does the size of ballast, as well as the choice of lamp characteristics. This situation demands full and accurate information on starting properties. Some description of the methods of making measurements, the difficulties encountered and the analysis of results would have been welcome.

Although the printed paper makes only brief mention of thermal switches, it is noted that the authors made further reference to this interesting type of starter in their spoken lecture.

An interesting discussion and demonstration of the properties of asymmetric glow starters has been given which may have left the impression that these devices are liable to be unsatisfactory in service. While not denying the factors which have been mentioned, it must be said that these features are a matter for the glow switch designer. If he gives them proper consideration, entirely satisfactory designs of asymmetric starter can be produced, and indeed are generally available. This is demonstrated in large-scale practice.

An interesting problem facing the circuit designer which has not been mentioned is the nicety with which the available starting voltage must be chosen in switchless circuits to avoid on one hand the likelihood of failure to start in adverse atmospheric conditions, and on the other hand the possibility of deleterious cold starting in ambient conditions conducive to easy starting. Perhaps the authors would care to enlarge on this point.

The paper has shown a number of different circuits for starting and operating fluorescent lamps, and discussed their merits. It is worth noting that a large part of the recently manifested increased freedom in the design of circuits arises from the tremendous improvement in lamp lives which has come about in the last decade. In particular, the greater latitude in cathode operating conditions allows circuits such

as the pulse start arrangement to be used, which would probably not have been acceptable in the early days of lamp development.

J. B. HARRIS: One of the problems of a large consumer concerned with the installation of many thousands of fluorescent lighting fittings under varying conditions of use is the simplification of their operation and maintenance. An essential feature, therefore, is the utilisation of control gear having a relatively long life and this, in practice, implies the elimination of consumable items such as starter switches.

The early experience gained in my department in regard to large scale installations indicated problems arising from frequent failure of starter switches, the matching of switches to operate individual fluorescent lamps and the storing of many types of switches due to the then lack of mechanical and electrical standardisation.

Fittings were often located in situations where access was difficult, art galleries and museums for instance; consequently replacement of a switch was a costly item on account of the labour charges involved.

We were very interested in the early development of "switchless" control gear, particularly if, in order to avoid storage and issue complications, normal untreated fluorescent lamps could be used.

A specification was drawn up some eight years ago and experience over this period has shown the general reliability in operation of control gear complying with our user requirements. One of our acceptance tests deals with the effect of starting on electrodes, and lamps are operated on a pre-determined switching cycle for a period of 1,000 hours.

Referring to Section (5.2.1), I should like to point out that we have conducted tests on lamps controlled by "switchless" gear, the results of which indicate lamp life and fitting maintenance superior to the minima quoted for switch start operation in British Standard 1853.

Referring to Section (5.2.3) I presume that the authors are referring to the use of "gearless" Tungsten Ballast circuits; if so it should be pointed out that in addition to "quick starting" there are many other economic and practical advantages which might influence their choice. Regarding nomenclature, terms such as "quick start," "snap start," "rapid start" and "instant start," as are employed in commercial literature, are descriptive in themselves and may be considered synonymous for all practical purposes. I am a little perturbed at the manner of use of the term "pulse start," for which I do not think there is an authoritative technical definition. Pre-heat starter switch circuits, for instance, rely on a pulse for starting and, to avoid misunderstanding, the term "pulse start" ought not to be applied to one basic type of "switchless" circuit.

H. G. JENKINS: The authors have drawn attention to the confusing nomenclature which has come into use to describe fluorescent lamps and their circuits. They would appear to have done little to lessen the confusion and make things easier for the user. Their proposal that the expression "instant start" should be reserved for the American high voltage cold starting circuit seems particularly unfortunate, since the cold starting circuit has long since ceased to be of any commercial significance.

There are only two broad classes of circuits in use: those which employ starting switches and those which do not. The confusion, if it exists, arises from a lack of appreciation of the real purpose of the new circuits. This is essentially to eliminate the starter switch with all its associated troubles and thus to simplify servicing in large installations where, as a previous speaker has pointed out, access to the fitting is frequently difficult. This is a matter of such importance, it seems safe to predict that circuits using starter switches will ultimately disappear, to be replaced by one or other

of the starterless circuits. It is unimportant whether the circuit in question is called "instant start," "quick start," "rapid start," "soft start," "trigger start" or what-you-will.

The authors have discussed at some length the so-called symmetrical glow starter. There is nothing new in this construction, which was used in this country when fluorescent lamps were first marketed at the beginning of the last war. The asymmetrical type is to-day used widely throughout the world and the difficulties to which the authors refer would seem to have been taken care of in the design.

D. H. HOLLOWAY: The introduction of the low voltage electrode fluorescent lamp in the American "rapid start" system will no doubt present difficulties in the British export market. Are there any advantages in this method in connection with the design of preheat transformers, and how does the lower voltage electrode affect ionisation and starting?

G. T. K. LARK: With reference to the pulse start variation of the "quick start" circuit, it was brought out in the paper that this effect may be achieved in two ways. By utilising the initial charging surge of the power factor capacitor in association with a portion of the choke winding, or an additional winding on the pre-heating transformer.

In practice, however, these circuits operate very differently. Where the capacitor choke method is employed, there are high-frequency harmonics generated in the choke winding which, under running conditions, cause distortion of the current wave form, and I suggest that reduction in lamp-life utilising this circuit is more probably due to this cause than the actual starting impulses so produced.

Another disadvantage of this circuit is that the power factor correction is less for a given-size capacitor. On the other hand, the transformer method introduces no wave form distortion, and experience has shown that this method does not cause a reduction in lamp life. Furthermore, the transformer winding, when correctly phased, gives a higher power factor correction for a given-size capacitor.

At several points during the paper it was stressed that adequate pre-heating of the cathodes must be provided, but no evidence was submitted as to what constitutes adequate pre-heating. This form of coated filament technique may be regarded as similar in behaviour to thermionic valves, and particularly small mercury vapour rectifier types. Under these conditions stable emission is achieved at a temperature between 900/950 deg. C., and I therefore suggest that it is only necessary for the pre-heating to raise the filaments to this temperature for satisfactory performance and life. In fact, over many years' experience, this has been fully established.

If, on the other hand, higher pre-heating temperatures are worked to, the only gain is a slight improvement in the rate of starting, with the disadvantage that there may be some volatilisation of the emissive material at starting, and certainly over-heating of the cathode under running conditions, due to the relatively high circulating current in addition to the arc current. Furthermore, more-than-necessary pre-heating energy lowers the efficiency of the circuit as a whole.

H. WINDEBANK: In Section 2 radioactive material is mentioned. According to a recent patent tritium is claimed as a stabiliser of the striking voltage of discharge devices. It has a half-life of 11 years and being a pure beta emitter presents no health hazard as no activity penetrates the glass envelope. Has a trace of this gas been tried in the filling of a fluorescent lamp to reduce the higher striking voltages to a narrower bracket? The latter part of Section (3.1.1) refers to pulse duration, but not of the rate of rise of potential. This I consider to be of major importance—the greater the rate of rise the greater the probability of start once the running voltage has been exceeded. This would account for the ease with which starting is accomplished in the higher frequencies. Some years ago a gas mixture for mercury-filled discharge tubes was

patented, which was reported to reduce the striking potential due to certain metastable conditions. It was, I believe, a mixture of 75 per cent. argon and 25 per cent. neon. Can the authors confirm this and comment on its use?

At a previous meeting of the Society we were told that it was advantageous to have a trace of nitrogen in the tube, from the point of view of lumen maintenance. Does this adversely affect the starting?

In Section (3.1.5) it is stated, " If preheating current produces an arc "; surely it is very desirable, in fact, some 20 per cent. extra life may be claimed according to a later section of the paper. Yet we do not find any recommended values of cathode resistance either in this paper or in BS 1853; we only find a starting current recommendation at 1.1-1.2 times the running current.

No mention is made of the minimum sustaining voltage of the starter switch relatively to the lamp-running volts. On the question of the radio interference capacitor, the authors give .006 Mfd as an optimum, yet BS 1853 give a figure of .02 Mfd. The peak voltages in either direction would indicate their importance in successful lamp-starting, but no mention is made of these values in Appendix D of the above specification, it merely shows diagrammatically a starter switch and says that the lamp shall start within one minute. The value of the radio interference capacitor may well be the cause of other forms of radio interference due to its association with the other component values in the circuit forming a relaxation oscillator, wherein sawtooth waveforms are generated, as shown by Strafford in 1938.

A. E. FOTHERGILL: In one of the experiments relating, I think, to the use of asymmetrical starters with capacitive tubes, although I heard the starter switch contacts opening, the current through the cathodes did not appear to be interrupted, and I would be grateful if the authors could explain this.

An earlier speaker raised the question of BS 1853. In this, Appendix D gives details of the starting tests and states that the preheating current using inductive gear must be 1.1 to 1.2 times the nominal running current. Appendix F also gives further details of the nominal preheating currents. All these figures are based on inductive circuits, because in the capacitive circuit the starting current is little different to the running current unless compensating devices are used, and in view of this it appears that the capacitively operated tube would not pass the starting test. Bearing in mind the large number of twin-lamp fittings now in use and the fact that few, if any, British manufacturers incorporate compensating devices in their gear, I am wondering if the authors would expect the life of the capacitively operated tube to be less than that of the inductive tube, and if so, to what extent.

J. CATES: The authors state in (3.1.1) that the striking voltage for positive pulses is higher than for negative pulses. The striking voltage is dependent on the field in the vicinity of the cathode. When a positive pulse is applied to the lamp, the cathode is at earth potential and the earthed fitting will have little effect in assisting starting. For a negative pulse, however, the anode is at earth potential and the pulse increases the field between the cathode and the earthed channel, enabling a lower pulse to be effective.

In (3.2.2) the authors refer to a glow type starter giving only a peak voltage of 350 volts. This is close to the crest value of the 240-volt supply voltage and suggests that the switch is giving no surge. Common experience shows that normal commercial asymmetric starters give adequate surge voltage in either direction to start the lamp quickly and reliably on A.C.

In (3.3.1) the authors must surely mean " an inch or less " and not " an inch or more," which does not make sense. In my experience an earthed wire of 0.25 mm.

diameter directly on the lamp is definitely more effective in adverse conditions than an earthed channel even half an inch from the lamp.

A simple explanation of the adverse effect of humidity mentioned in (3.3.3) is that under conditions of maximum starting voltage the surface film of moisture consists of patches electrically insulated from each other. These behave as an effective electrostatic shield to the earthed channel and reduce its effectiveness. At very high humidities the moisture film tends to be continuous and, as pointed out by the authors, it will then itself tend to act in the same manner as an earthed stripe on the lamp, or an earthed channel close to the lamp.

A. E. BIRD: I regret that the paper does not provide more data on performance in the field. My general opinion is that fluorescent lamps in recent years have had most of the bugs taken out of them and become really uniform reliable products. The effect of various service circuit conditions are now showing up, whereas previously they were obscured. My experience indicates that a good thermal starter is easiest on the lamp. Glow starters seem more variable and can give rise to cold starting with adverse lamp effects. " Instant start " gear, if well made, can give reliable reproducible results in service. I regret that no mention of lead/lag circuits is made in the paper. The low starting current and tendency to cold starting as well as poor crest factor in capacitive circuits, according to a paper by Lowry, can give less than 50 per cent. normal lamp life. Recent data made available to us, over a wide range of installations in this country with similar lamps, shows that " instant start " circuits (in half installations) give substantially better lamp lives than the other half of the installations using lead/lag circuits with glow starters.

With regard to curves showing starting voltage against temperature, we find that with metal stripe lamps the curve is flatter at 0 deg. or below whereas with siliconed lamps it is flatter at the higher temperatures. Thus for cold, outdoor installations it is preferable to use metal stripe lamps, and for enclosed fittings where lamps run rather hot there is an operating advantage as well as an economic one in using siliconed lamps.

A. G. PENNY: I feel that the authors and some of those who have entered into the discussion are to be criticised for their lack of interest in the problems of starting fluorescent tubes in overseas countries.

In the United Kingdom the reliable starting of fluorescent tubes is, as the authors have shown, easily achieved in a variety of ways. This is largely because conditions are favourable; earth connections are usually available, temperature and voltage variations are relatively small, etc. On the contrary, conditions in many overseas countries are much more difficult; earthing is relatively uncommon, voltages may vary over very wide limits, temperatures from minus 20 deg. C. or lower to plus 60 deg. C. and humidity over the whole range. Moreover, supervision of installations is often only possible with relatively unskilled labour, so incorrect wiring, dirty contacts and similar troubles are all too frequent.

In a country such as ours where the export markets are vital, I think designers should not be content until they can make lamps and gear which will give reliable starting overseas, and if we sell it as " quick " starting, it ought to be quick under the conditions I have described. To be specific, may I suggest that " quick " ought to mean starting within two seconds without an earth, at a temperature of minus 20 deg. C. on an electric supply 15 per cent. below nominal? I believe that overseas customers would welcome such a performance even at some sacrifice in life, which is now to be measured in years rather than hours.

May I also comment on Mr. Bird's remarks about shortening of lamp life which he has experienced on capacitative circuits. It is known that some designs of lamps

are adversely affected by such circuits, but there are others in which the effect is very small. Some lamp makers, at least, are able to offer lamps which give their full declared life in such circuits.

The AUTHORS (in reply): When writing this paper, we were confronted with the difficulty of presenting a considerable amount of information on the starting characteristics of lamps, in various types of circuit, in such a way as to distinguish separately the relevant factors. The space which has been devoted to the problems of the circuit design, methods of making measurements and so on, may appear to Mr. Williams to be inadequate, but our intention was to concentrate mainly on the behaviour of the lamp itself and give examples to show how other circuit components meet the lamp requirements. As an example of a starter switch, the glow switch was given detailed treatment in preference to the thermal switch, mainly because, particularly since the introduction of the "universal" type, the glow switch is more widely used. The demonstrations showed in an exaggerated form the difference in behaviour between symmetrical and asymmetrical switches, and although such effects would not be so noticeable with commercially available switches, overall better performance is given by the symmetrical type in unfavourable conditions.

The range of voltage in which cold starting may be avoided but reliable starting guaranteed, in adverse circumstances, is strictly limited, as Mr. Williams points out. It can be seen from Fig. 10 that a range of about 50 volts exists for the 5-ft. lamp. In practice it is the achievement of reliable low temperature starting that presents the more difficult problem.

Mr. Harris' objections to the use of starter switches appear to be based on experience of early types, and we have indicated some of the reasons for the unsatisfactory behaviour to which he refers. Glow switches available now are the result of much development work and will outlast several lamps, so that switch replacement costs do not reach a high figure. In situations where prompt replacement of a failed lamp is not possible, the use of a "no blink" type of switch can give a further reduction in long term costs.

Starting circuit nomenclature arises more out of usage than by authoritative definitions, and provided the terms used are not ambiguous they are an essential means of differentiating basically different types of circuit. With regard to the term "pulse start," we feel that it is necessary to distinguish a circuit which has less stringent lamp requirements than the "quick start" circuit from which it is derived, and there is no real likelihood of confusion with starter switch circuits. More objection to the term "instant start" as used in this country could be raised, firstly because it is not accurately descriptive, and secondly because it conflicts with pre-established terminology.

Mr. Jenkins appears to accept our division of three circuit types, but then rejects the first as obsolete and predicts the ultimate elimination of the second. The extinction of the starter switch will, however, depend on the development of switchless circuits with none of the limitations of those at present available, and here one could envisage a return of the cold-starting type following improvements in cathode design. In the meantime the majority of circuits under the starterless heading have special lamp requirements, and as these requirements are not always similar it is essential that at least some distinguishing names should be retained.

An example of a special lamp requirement is in the American "rapid start" circuit which Mr. Holloway has mentioned. In this case the cathode is of the triple-coil design, able to hold a larger amount of emissive material for a given weight of tungsten than the coiled coil type. A longer cathode life is thereby achieved and at the same time the power requirements for cathode heating are reduced. The cathode temperature is sufficient to give full emission for starting but, owing to the low resistance of the

cathode, the voltage across it is never sufficient to produce a local arc. One disadvantage of this is that the cathode is more critical with regard to pre-heating current than the conventional type for the following reason. When a local arc occurs across a cathode coil, the voltage across it becomes almost independent of the current so that the temperature of the portion of the coil coated with emitter does not increase if the pre-heat current increases. By suitable design of the cathode it can be arranged that the maximum temperature reached is insufficient to evaporate the emitter. As this temperature regulating effect of the cathode arc is absent in the rapid start lamp, it is important that the pre-heat current be kept within close limits; difficulties then arise because of contact resistance in the lamp holders.

We do not agree with Mr. Lark that short lamp life in pulse-start circuits is caused by high frequency harmonics. Tests on both choke tapping and transformer types show the same reduction in life compared with starter switch or quick start circuit. The cause of the life reduction is the glow to arc transition at the cathode during the starting period. Damage to the cathode may be minimised by ensuring that full emission temperature is reached as quickly as possible; this means that the pre-heat current must be more than is necessary just to achieve the minimum of cathode heating. Under running conditions the cathode current is, in any case, reduced automatically by the arrangement of windings on the auxiliary transformer.

The comparison made by Mr. Lark between thermionic valve cathodes and fluorescent lamp cathodes is not strictly valid because the latter operate in a gas atmosphere which appreciably reduces the rate of evaporation of emissive material and higher cathode temperatures are therefore permissible. There is also, in the case of lamp cathodes, the temperature regulating effect of the local arc, mentioned in our reply to Mr. Holloway.

Mr. Windebank refers to the use of tritium as an ionising agent in discharge tubes; it has not, to our knowledge, been tried in fluorescent lamps and we doubt if any advantage would be gained except perhaps where cold-starting is desired. The supply of electrons from pre-heated thermionic cathodes is far greater than could be obtained from permissible quantities of radio-active material. In addition, the present cost of tritium would make its use in lamps prohibitively expensive. As to neon-argon mixtures, it is true that certain proportions of these gases will give a lower striking voltage than either neon or argon alone. However, the introduction of neon into lamps of conventional design results in a lower efficiency, because electrons lose more energy in elastic collisions with neon atoms, which are lighter than argon atoms. The presence of any diatomic gas, such as nitrogen, increases the striking voltage, but the small quantity of nitrogen which may be introduced to improve lumen maintenance ceases to have any effect on starting after the lamp has been run for a short period.

Another of Mr. Windebank's remarks concerns the rate of rise of potential and its relationship to the pulse striking voltage of a lamp. Measurements were made by using a pulse generator, briefly described in Section (3.1.1), and the sharpness of the leading edge of the pulse was varied by introducing a low-pass filter between the generator and the lamp. It was found that provided the initial rate of rise of potential was greater than about 10 volts per micro-second, it had no effect on the lamp striking voltage. In a starter switch circuit, the radio interferences suppression capacitor affects the rate of rise of potential, but unless the capacitance is above .05 microfarad the rate of rise exceeds the above figure by a considerable margin. Whilst on the subject of suppression capacitor values we would point out that the .02 microfarad specified in B.S. 1853 is for the purpose of a particular starting test; our experience is that .006 microfarad is better for lamp starting and is still sufficient to reduce radio interference generated by the starter switch. We are familiar with the relaxation

oscillations to which Mr. Windebank refers but have never found them to be a source of radio-interference. Towards the end of life some lamps generate radio frequency oscillations by an obscure mechanism that is quite independent of the external circuit conditions; in this case the suppression capacitor across the lamp acts as a shunt path for the radio frequency currents.

On the question of cathode resistance there are a number of factors to be taken into account, for example coil pitch, distribution of emitter on the wire, and optimum operating temperature for the particular emitter, so no useful purpose would be served by specifying the resistance alone. Pre-heat current specification would be more useful, but the recommended values in B.S. 1853 are only intended for test purposes.

The demonstration referred to by Mr. Fothergill was no doubt the low-pulse asymmetrical glow switch failing to start the lamp one way round. Although the switch contacts were opening, the whole of the pulse energy was dissipated in the switch, causing its immediate reclosure. Interruption of the cathode current was therefore too brief to be perceptible. With regard to the pre-heat current in capacitive circuits, Mr. Fothergill presumably means that a lamp which passes the B.S. starting test would not necessarily be satisfactory for capacitive circuits. Although the pre-heat current is undoubtedly lower than normal, if no compensating arrangement is employed, the lamp cathodes reach full emission temperature, but rather more slowly. A recent paper by Lake* on the subject of short life in capacitive circuits puts the blame largely on glow switches of unsuitable design. Asymmetrical switches are shown to increase cold starting tendencies by their rectifying action, and certain gas mixtures in the switch cause high frequency oscillations, again leading to cold starting.

The explanation given by Mr. Cates for easier starting with negative pulses does not conflict with that given in Section (3.1.1), but it is not necessary to assume the presence of adjacent metal. The curves depicted in Fig. 1 relate to lamps far removed from earthed objects, a situation that is not unknown in practical installations and has to be allowed for in the design of glow switches. A peak voltage of only 350 volts in one direction is not uncommon for an asymmetrical starter. The point of the example in which this figure was quoted, was to show that a peak of 650 volts in the other direction is required to start lamps reliably, whereas for a symmetrical starter 500 volts is required. We are rather surprised by Mr. Cates' apparent unawareness of the need for starters to operate on R.M.S. voltages as low as 180, the peak of which is only 254 volts.

Perhaps the wording in the second paragraph of Section (3.1.1) is not sufficiently precise, but the intended meaning is that the earthed fitting may be more than one inch away from the lamp, within reasonable limits, and still be more effective than the wire. By adverse conditions we presume that Mr. Cates means high humidity in which case a lamp with an attached wire is superior only to a lamp that has not been silicone treated. We cannot agree with Mr. Cates' explanation of the humidity effect, for when the surface film of moisture is discontinuous no effect on the lamp striking voltage is observed; and this is, of course, the reason for the effectiveness of silicone treatment. When determining the dependence of striking voltage on surface resistance we used a lamp treated with a wetting agent and placed in a controlled humidity enclosure. Resistance measurements between various points of the tube surface confirmed the existence of a continuous conductive film.

The preference Mr. Bird shows for thermal starters may be based on the shortening of lamp life caused by slow-closing, high-pulse glow switches. Provided that a glow switch acts rapidly, the lamp voltage during an incipient cold start is high enough to reclose the switch immediately and allow a further period of pre-heating. As explained in Section (3.2.2), symmetrical switch construction ensures rapid action in both inductive and capacitive circuits. Under these conditions we have found that

* Lake, W. H., Illum. Eng., **51**, 689 (1956).

thermal and glow starters give equal life. We agree with Mr. Bird that continuous pre-heat circuits, generally referred to as quick-start in the paper, give appreciably better lamp life.

The different behaviour of siliconed and metal-striped lamps at extremes of temperature, mentioned by Mr. Bird, has not come to our notice before. It seems possible, however, that at low temperatures humidity conditions are in fact involved; for example, the existence of a water film containing dissolved salts is possible on a tube even below freezing point. The surface conductivity of the film can increase the effective area of the stripe and improve starting At high temperatures, siliconed lamps would start more easily if the distance of the fitting were such as to provide a greater earth capacitance than a metal stripe

Mr. Penny sets a target for lamp circuit designers that is rather disconcertingly high, and we seriously doubt whether any electrical appliance could be made immune to the effects of incorrect wiring, for instance. Those of Mr. Penny's customers who are unfortunate enough to experience the combination of adverse conditions stated by him, probably also suffer from frequent and lengthy supply breakdowns; we therefore venture to suggest that oil lamps might be recommended as more reliable light sources in such circumstances.

Fellowship

The Council has accepted the following application for Fellowship of the Society:—
Mr. F. P. Bentham.

Register of Lighting Engineers

The Council has accepted the following applications for inclusion on the Register of Lighting Engineers:—
Mrs. J. L. Stewart, Mr. J. R. Arlett, Mr. S. J. Chasey, Mr. A. Robinson, Mr. W. J. Burland, Mr. H. G. Pantall, Mr. D. R. Griffiths, Mr. K. E. Kerridge.

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society and their names have been added to the list of membership:—
CORPORATE MEMBERS:—

Abbott, A. J.	9, The Avenue, Nunthorpe, MIDDLESBROUGH.
Dillon, T. J. (Miss)	Queen Elizabeth College, Campden Hill Road, LONDON, W.8.
Edwards, E. F.	76, Woodlands Avenue, Eastcote, RUISLIP.
Ella, G. H.	Flat 2a, High Peak Hotel, Forest Road West, NOTTINGHAM.
Gardner, G.	12, Peacock Drive, Heald Green, Cheadle, CHESHIRE.
Hammond-Gabbitas, W.	3, Oak Hill, Epsom, SURREY.
Nicholson, J. E.	No. 2 Flat, The Rangers, Woodmancote, Dursley, GLOS.
Parker, P. D.	13, Broxbourne Road, Orpington, KENT.
Raj, G. V.	B. & C. Mills, Perambur Barracks, Madras 12, INDIA.
Rowlands, E.	6, Abbotts Drive, North Wembley, MIDDX.
Sharp, E. F.	The General Electric Co., Ltd., Osram Dept., Magnet House, Victoria Bridge, MANCHESTER 3.
Simons, R. H.	28, Aylmer Road, London, N.2.
Wilson, A. A. R.	3, River Road, Maraval, TRINIDAD, N.W.I.
Zapp, M. C.	93, Hull Road, Anlaby, YORKS.

Extraordinary General Meeting

At an extraordinary general meeting of the Society held at the Lighting Service Bureau, 2, Savoy Hill, London, W.C.2, at 6 p.m. on March 26, 1957, Special Resolutions concerning amendments to the Memorandum and Articles of Association and the By-laws of the Society, and to the name of the Society were considered. Special Resolutions 1 and 2 (Memorandum and Articles of Association) were approved; Special Resolution 3 (By-laws) was amended so that the initials to be used by Diploma Members shall be Dip.M.I.E.S. and the amended resolution was approved; Special Resolution 4 (name of the Society) was not carried and the name of the Society therefore remains as at present.

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